

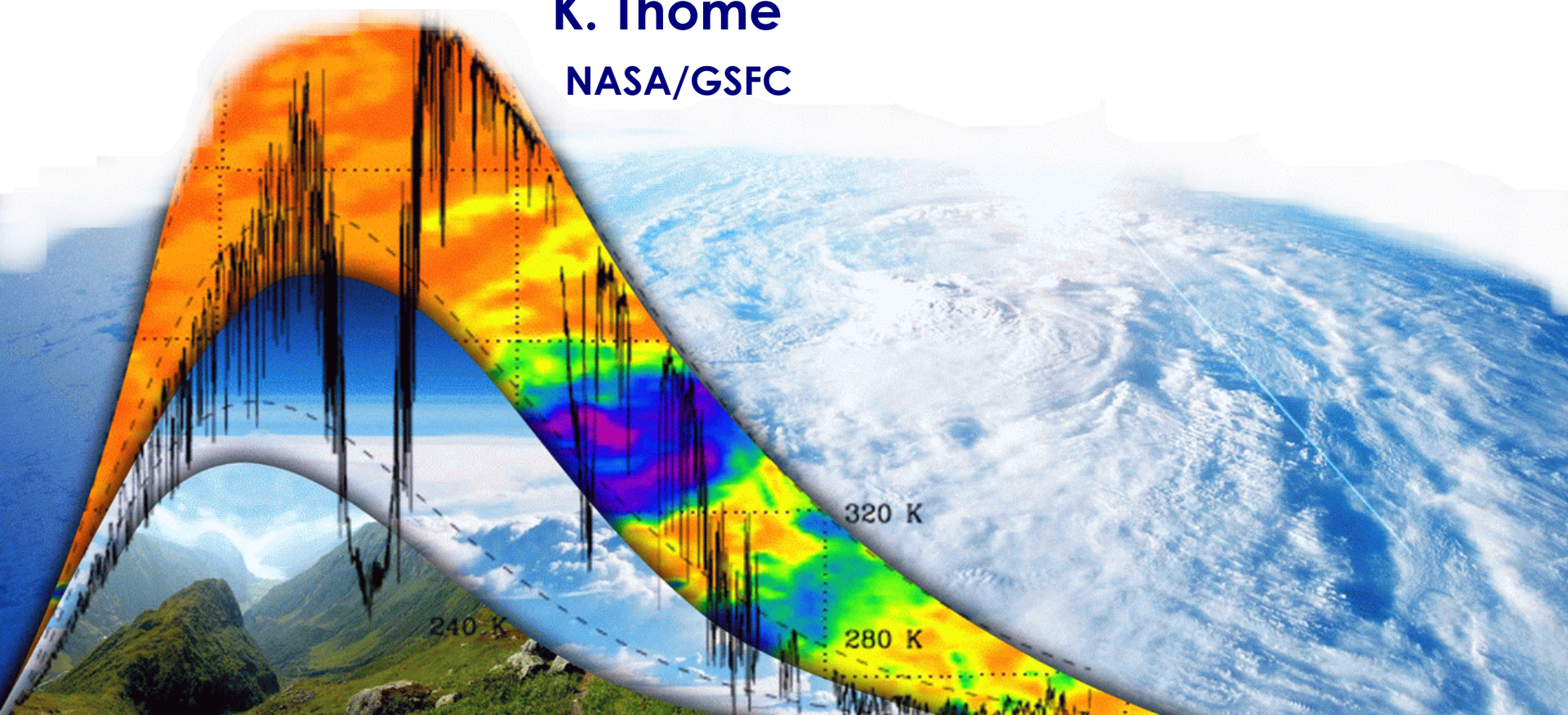


GODDARD SPACE FLIGHT CENTER

Reflected Solar Calibration Demonstration System - SOLARIS

K. Thome

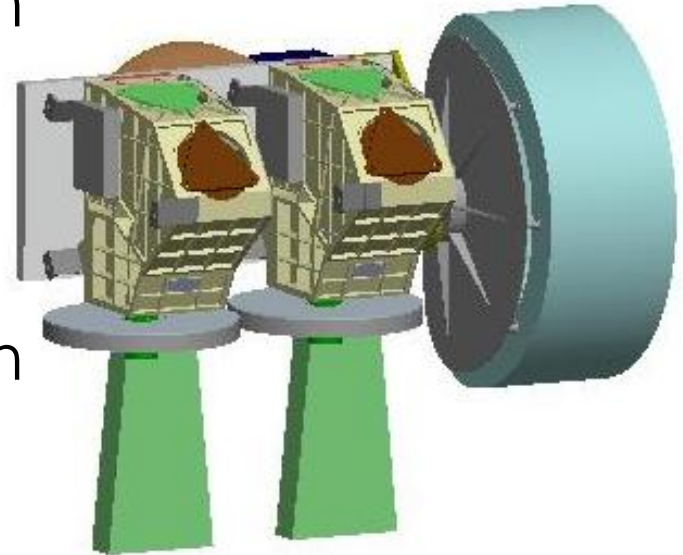
NASA/GSFC



RS instrument

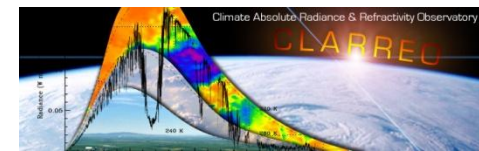
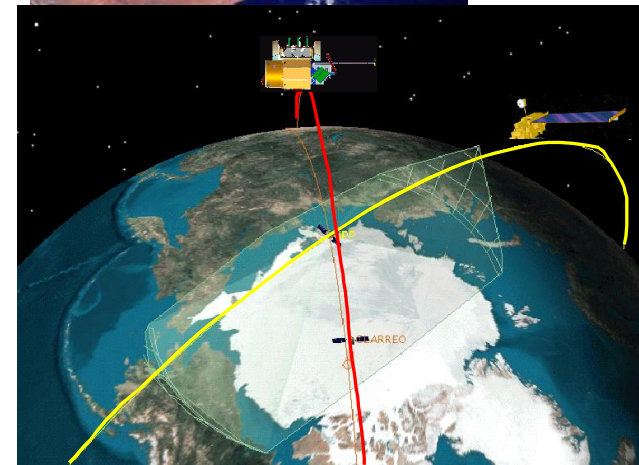
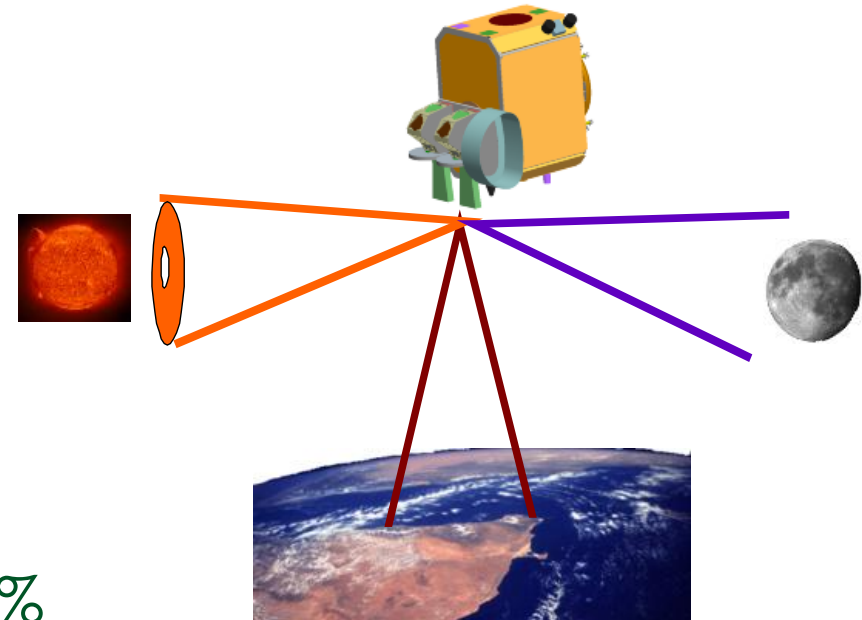
Reflectance must be traceable to SI standards
at an absolute uncertainty $<0.3\%$

- Spectral range from 320 to 2300 nm
- 500-m GIFOV
- 100-km swath width
- Goal of sensor design is to reduce complexity for accurate calibration
- Offner spectrometer with two separate entrance apertures
- Commonality of design of two boxes aids in calibration



Operating Modes

- Reflectance obtained from ratio of radiance viewing earth's surface to measurements of irradiance while viewing the sun
- Three basic operating modes for RSS instrument
 - Nadir Data Collection (>90% data collection time)
 - Solar Calibration
 - Inter-calibration of other on-orbit assets
- Verification of calibration drives the need for lunar views



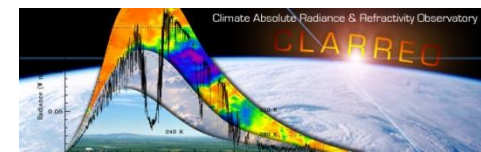
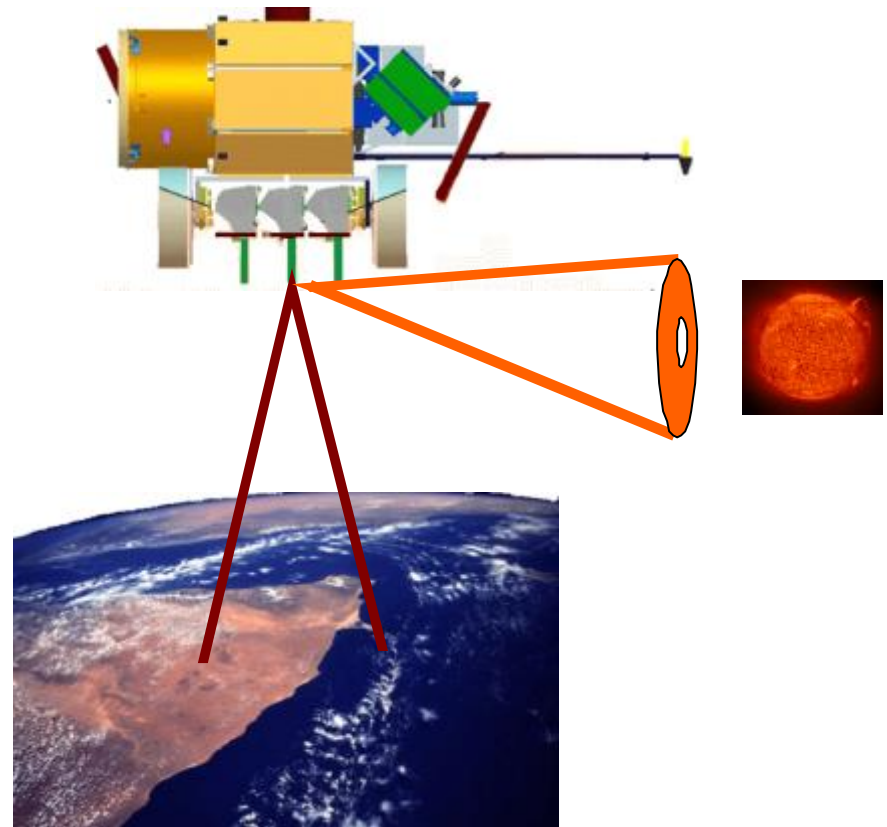
Reflectance approach

- Retrieve reflectance via ratio of earth-view data to solar-view data
 - Single detector scans entire solar disk
 - Response of i^{th} detector is

$$R_{i,\lambda}^{\text{sensor}} = \frac{\sum_{x_{\text{solar}}} \sum_{y_{\text{solar}}} S_{i,\lambda}^{\text{solar}}(x'_{\text{solar}}, y'_{\text{solar}})}{(T_{\text{attenuator}} A_{\text{attenuator}}) E_{\text{solar}}}$$

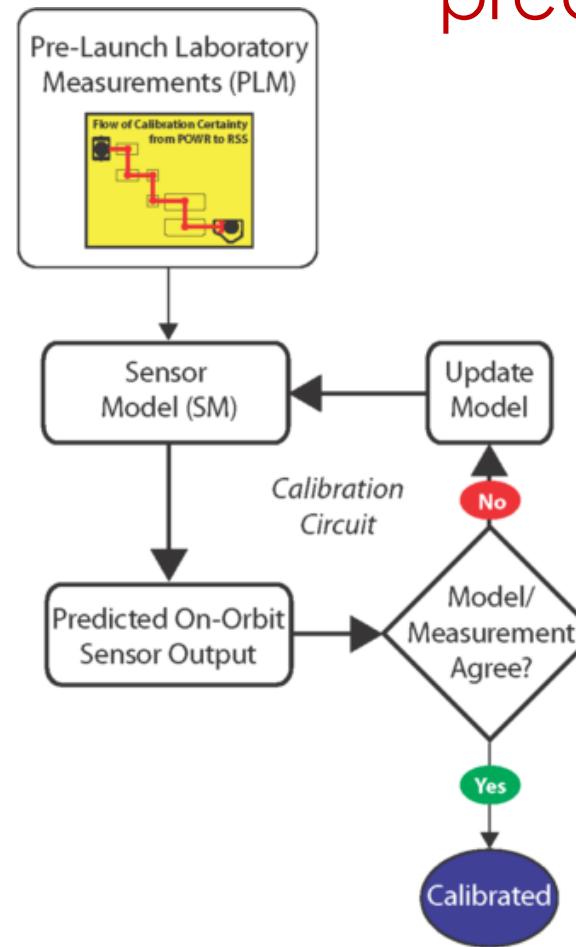
- Bidirectional reflectance distribution function (BRDF) is

$$BRDF_{i,\lambda}^{\text{earth}} = \frac{L_{i,\lambda}^{\text{earth}}}{E_{\text{sun}} \cos \theta_{\text{solar}}} = \frac{S_{i,\lambda}^{\text{earth}}}{R_{i,\lambda}^{\text{sensor}} A_{\text{sensor}} \Omega_{\text{sensor}}} \frac{(T_{\text{attenuator}} A_{\text{attenuator}}) R_{i,\lambda}^{\text{sensor}}}{\cos \theta_{\text{solar}} \sum_{x_{\text{solar}}} \sum_{y_{\text{solar}}} S_{i,\lambda}^{\text{solar}}(x'_{\text{solar}}, y'_{\text{solar}})}$$



Calibration approach

Successful transfer to orbit through accurate prediction of sensor behavior



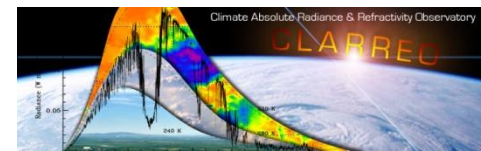
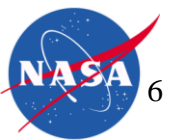
- Characterize sensor to SI-traceable, absolute radiometric quantities during prelaunch calibration
- Determine geometric factors for conversion to reflectance
- Key is to ensure prelaunch calibration simulates on-orbit sources

Key error terms

Developed a preliminary error budget based on a nominal design for the RS sensor

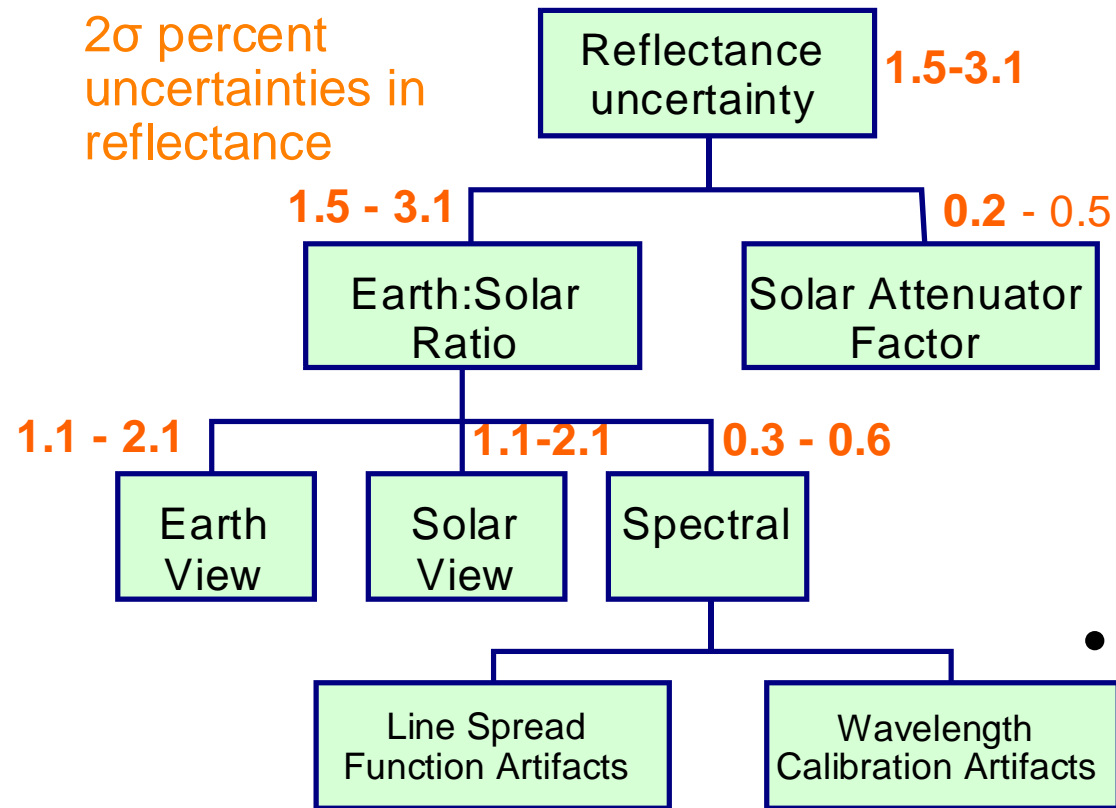
- Key uncertainties are
 - Geometry differences between the solar and earth views
 - Knowledge of attenuator behavior when viewing sun
 - Sensor behavior
 - ◆ Detector linearity
 - ◆ Noise behavior
 - Polarization

$$BRDF_{i,\lambda}^{earth} = \frac{S_{i,\lambda}^{earth}}{R_{i,\lambda}^{sensor} A_{sensor} \Omega_{sensor}} \frac{(T_{attenuator} A_{attenuator}) \langle R_{\lambda}^{sensor} \rangle}{\cos \theta_{solar} \sum_k \sum_l S_{k,l}^{solar} r_{k,\lambda}^{flat\ field}} \frac{a_{sensor}^{straylight} \omega_{sensor}^{straylight} a_{attenuator}^{straylight}}{r_{i,\lambda}^{flat\ field} r_{i,\lambda}^{nonlinearity} r_{i,\lambda}^{polarization}}$$



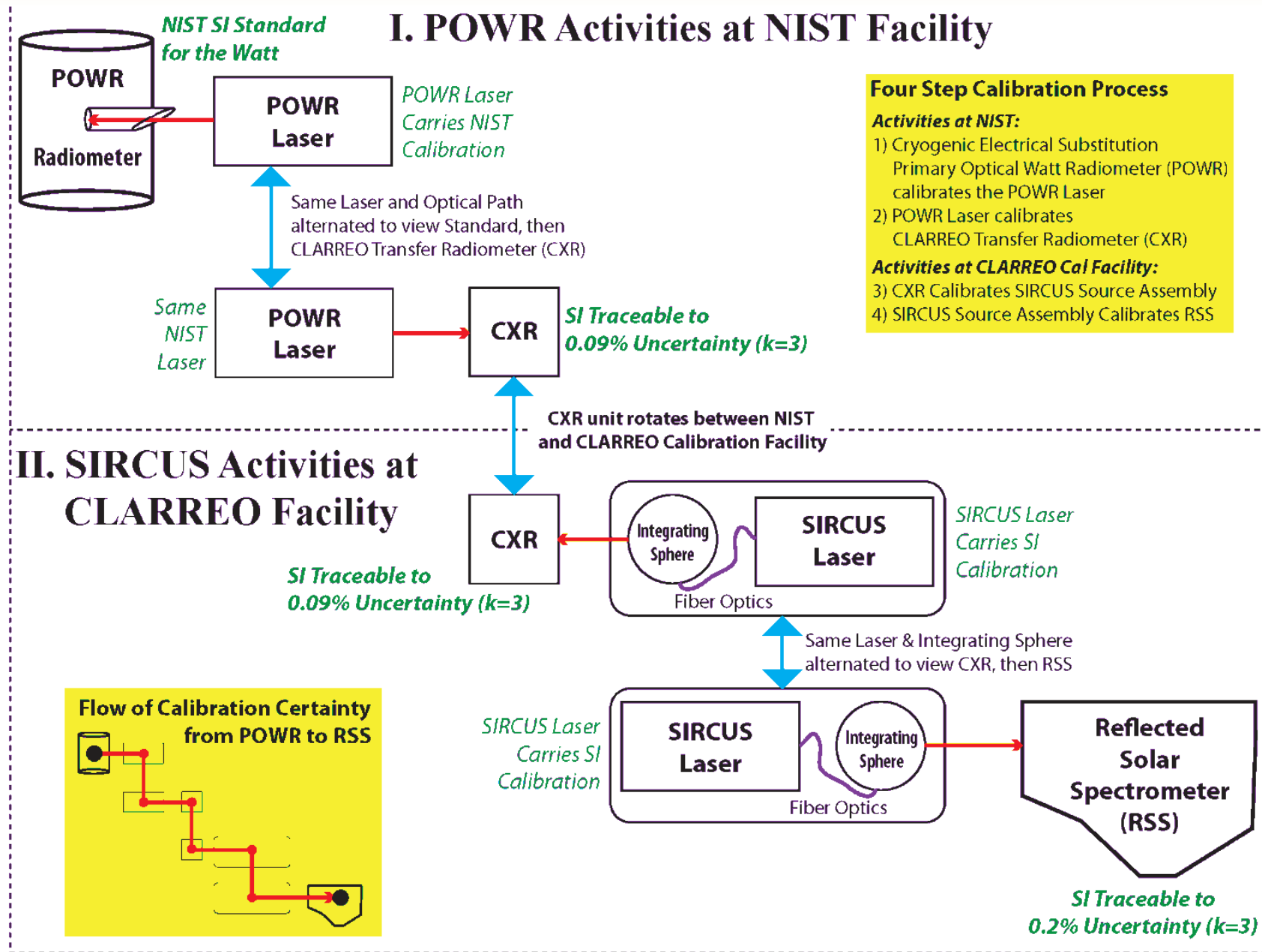
Aerospace Error Budget

2 σ percent
uncertainties in
reflectance



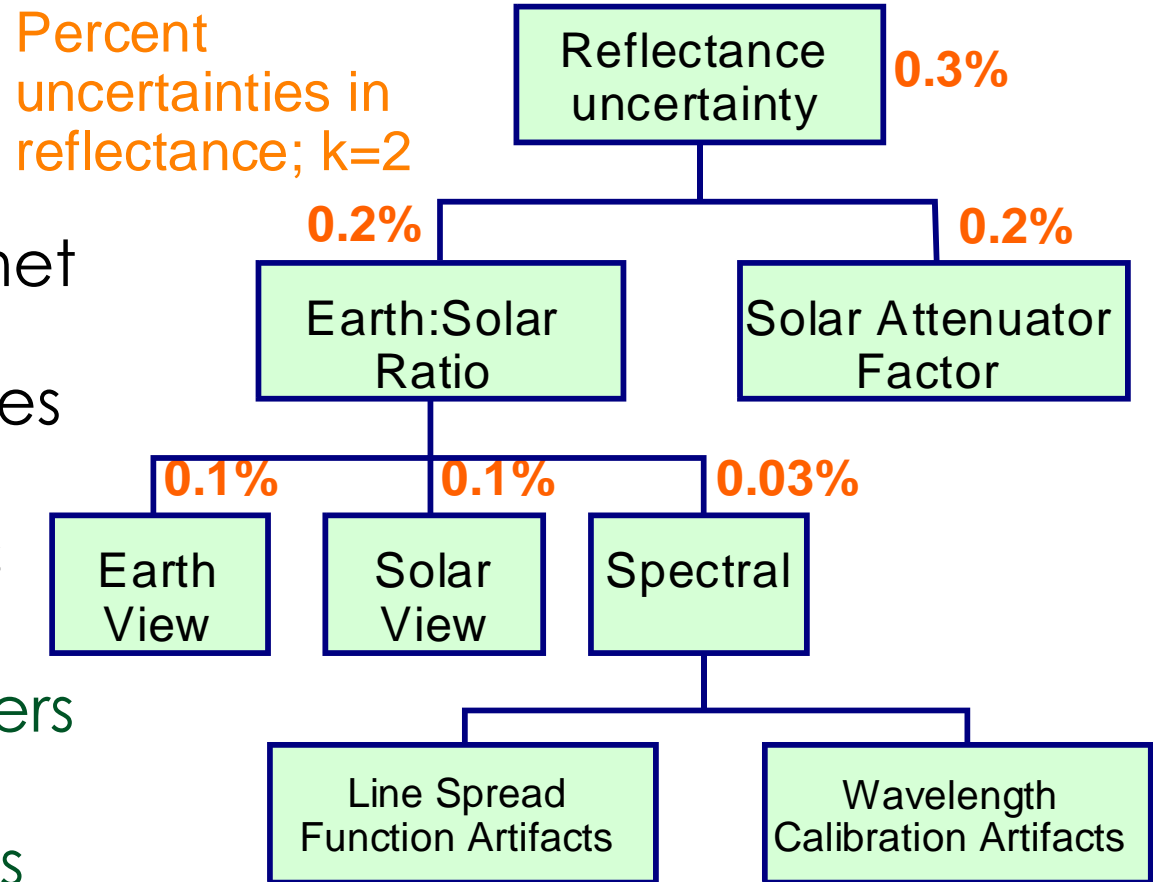
- Aerospace study led to estimated error budget
 - Based on earth view/solar ratio, i.e. reflectance
 - Assumed typical, available facilities in commercial vendors
- Solar attenuator factor is uncertainty caused attenuator behavior
- Earth and solar view errors are uncertainties in those measurements

SI traceability and Stray Light



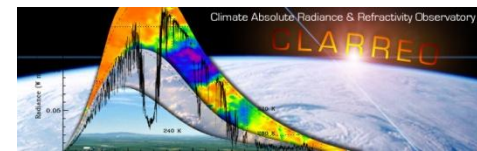
SIRCUS-based Error Budget

- Radiometric calibration requirements of RS instrument can be met with currently-available approaches
- Requires inclusion of NIST-based methods
 - Detector-based transfer radiometers
 - Narrow-band SIRCUS approaches
 - Hyperspectral image projector-based scene projections



Calibration Demonstrator System

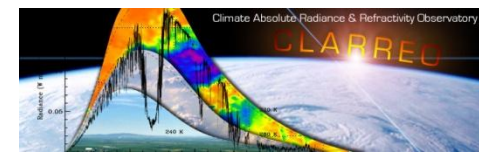
- SOLar, Lunar for Absolute Reflectance Imaging Spectroradiometer (SOLARIS)
 - Technology demonstration of
 - Thermal control of attenuators and detector
 - Design and production of optics
 - Depolarizer technology
 - Test prelaunch calibration methods
 - Evaluate reflectance retrieval
 - Demonstrate transfer-to-orbit error budget showing SI-traceability



CDS – Calibration protocols

Calibration demonstrator provides tests of laboratory characterization approaches

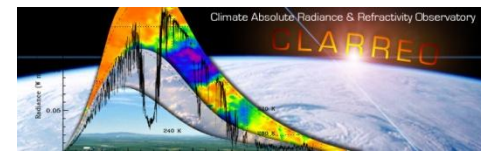
- Robust, portable tunable-laser facility including transfer radiometers with sufficient spectral coverage
- Broadband stray light and polarization systems of sufficient fidelity
- Depolarizer technology
- Thermal control of attenuators and detector needs to be proven
- Development of physically-based spectrometer models including well-understood error budgets



CDS – Reflectance retrieval

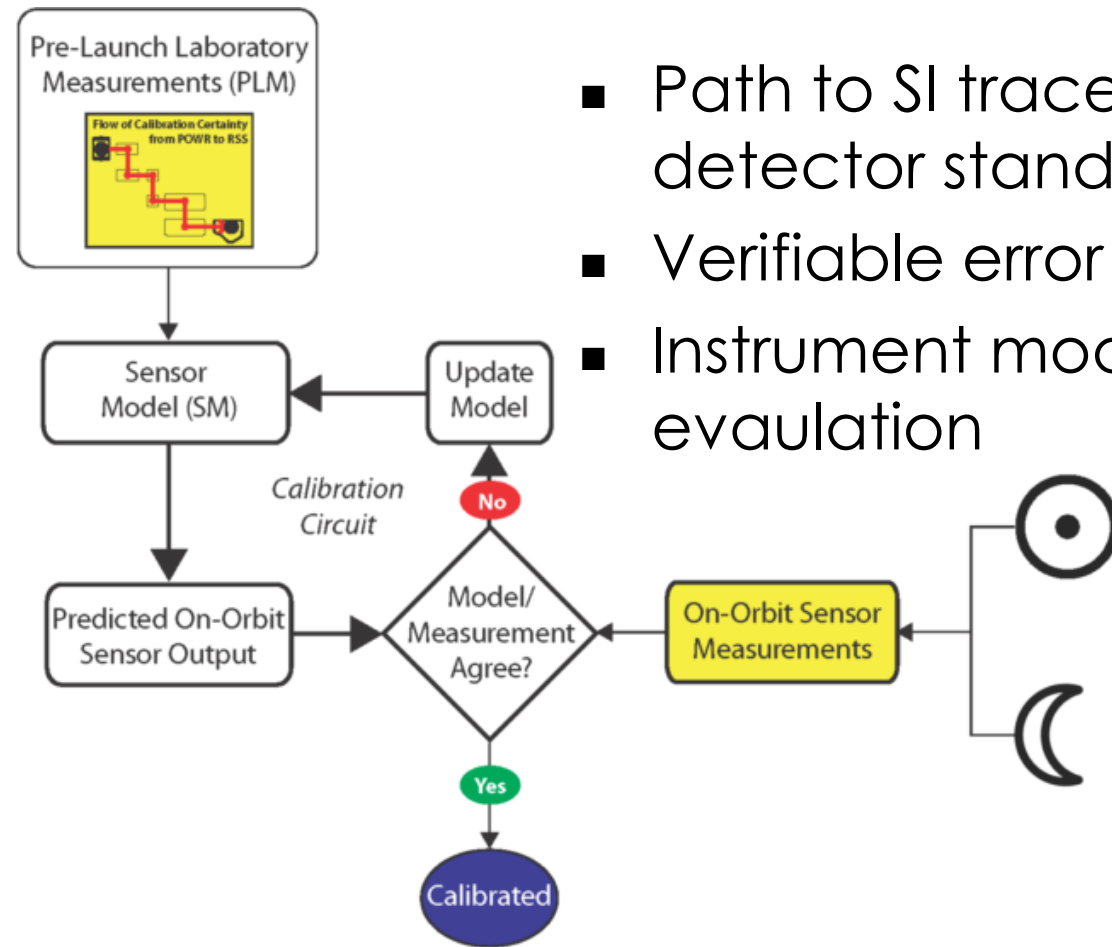
Operating demonstrator in the field will provide
check on instrument models

- Retrieve reflectance by taking the ratio of the solar irradiance and the signal from the scene
 - Instrument model development for stray light and other geometric effects
 - Correction techniques for solar attenuators
- Validation of reflectance done in laboratory & field
 - Currently available laboratory equipment
 - Compare with state-of-the art field approaches
- Sea level and mountain-top observations of sun and moon
- Cross-comparisons with other system



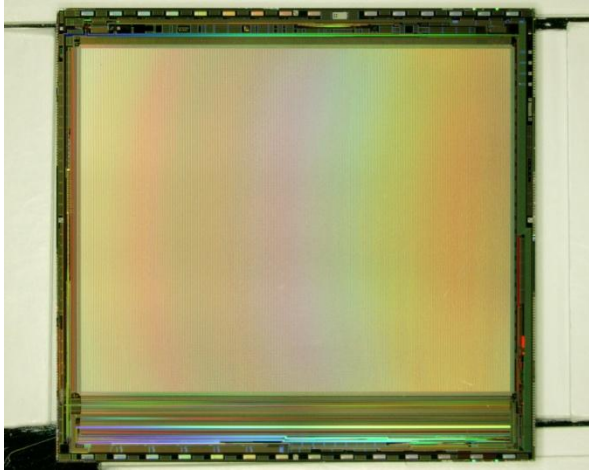
CDS – SI traceability and transfer to orbit

Develop and check calibration protocols and methods

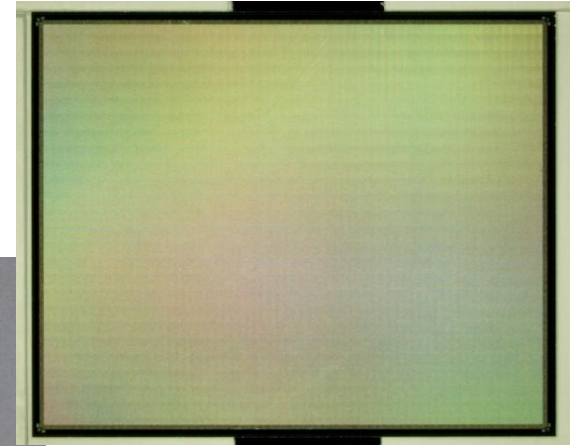


- Path to SI traceability (source and detector standards)
- Verifiable error budgets
- Instrument model development and evaluation

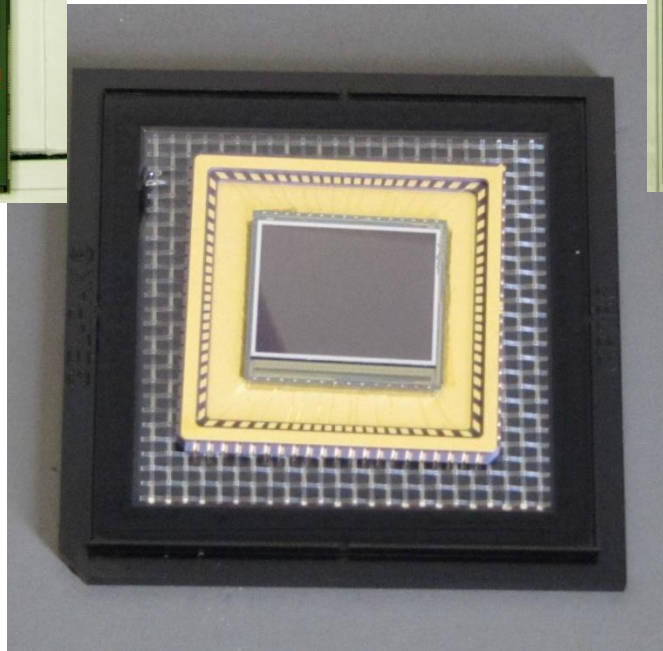
SOLARIS Silicon Detector



ROIC



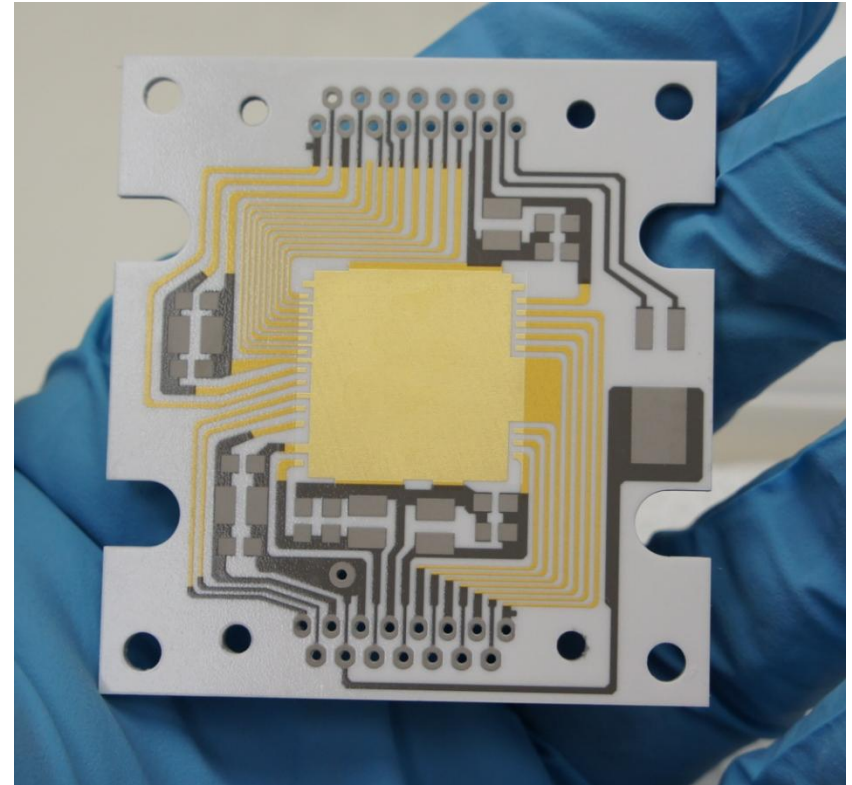
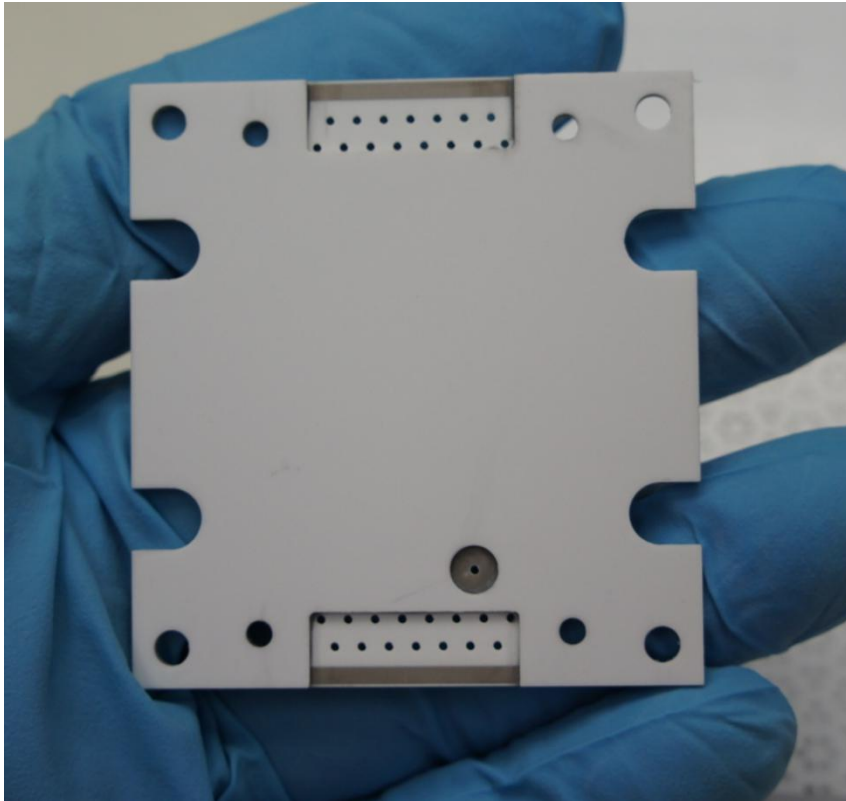
Detector with In Bumps



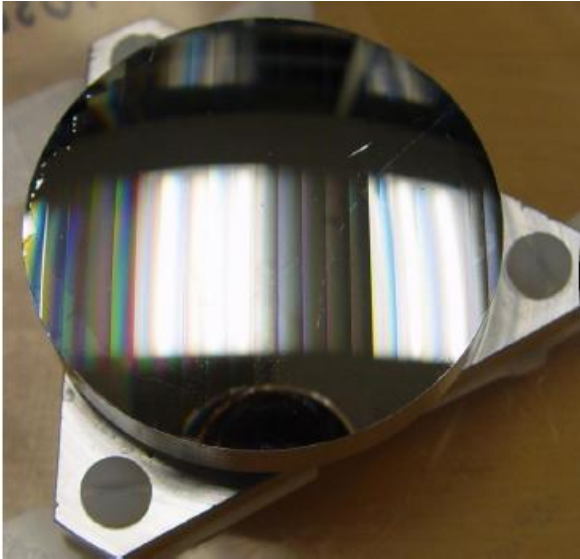
Detector Hybrid in a LCC carrier

Ceramic Boards Bonded Together

Thermal Testing – The boards were cycled to 373 K for 2 hours, then 173 K for 2 hours with no damage



Optical Components

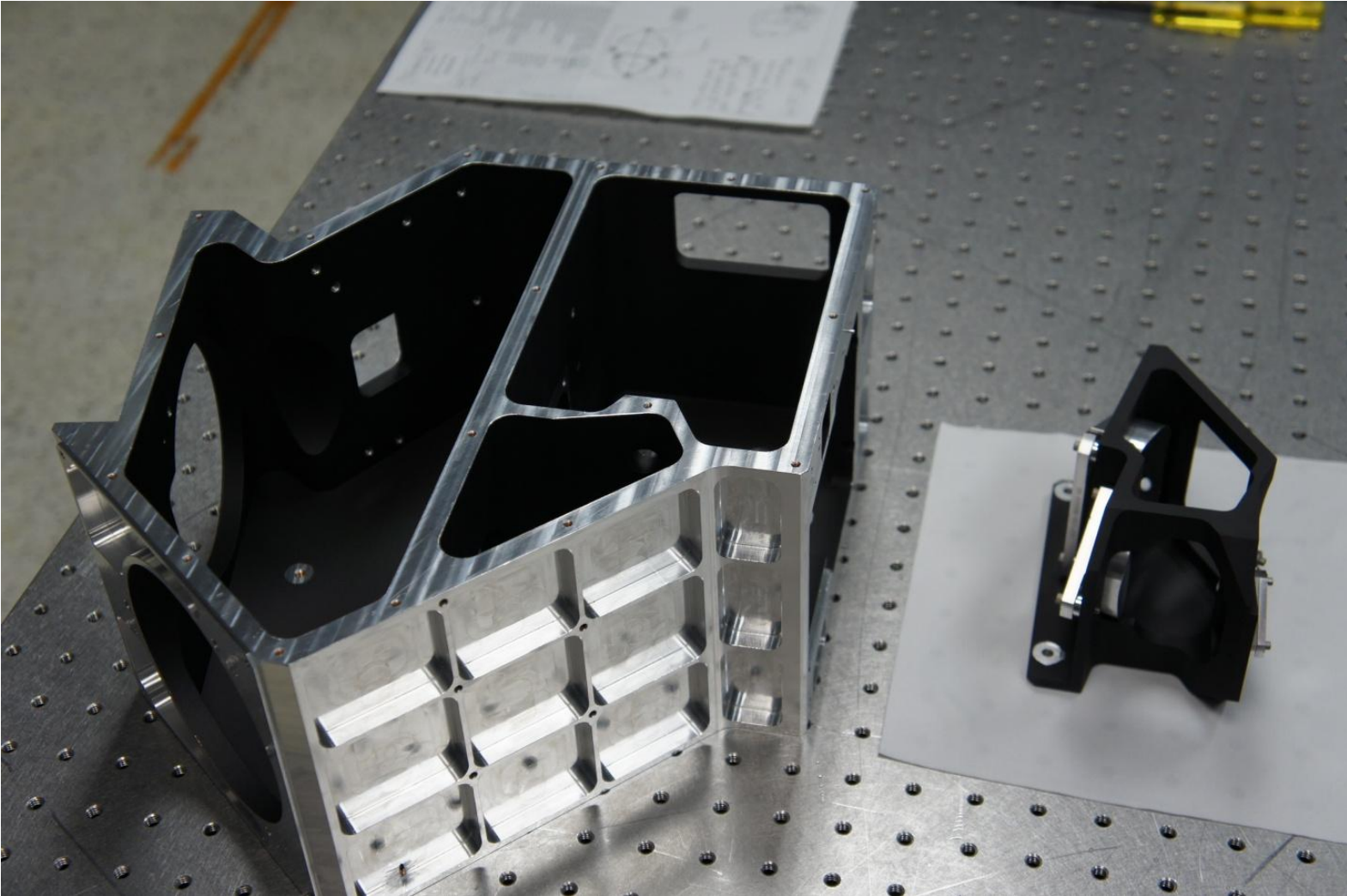


First unit grating replica

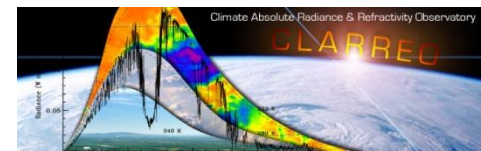
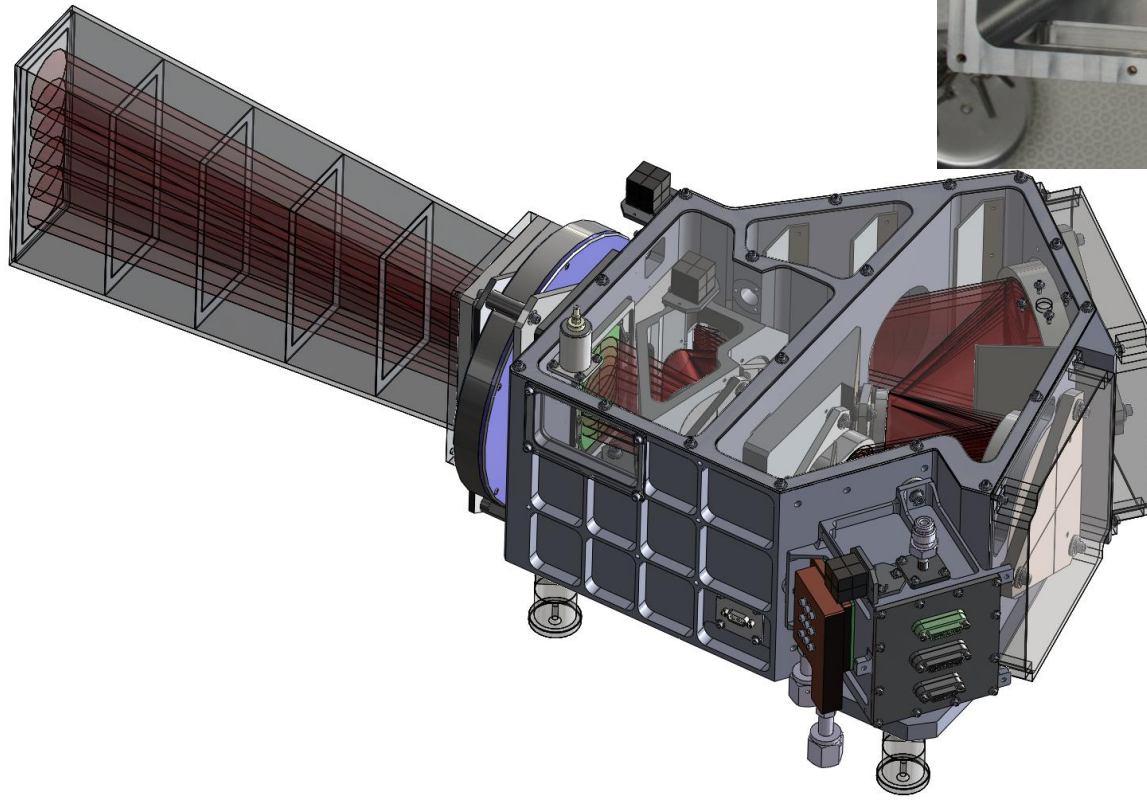
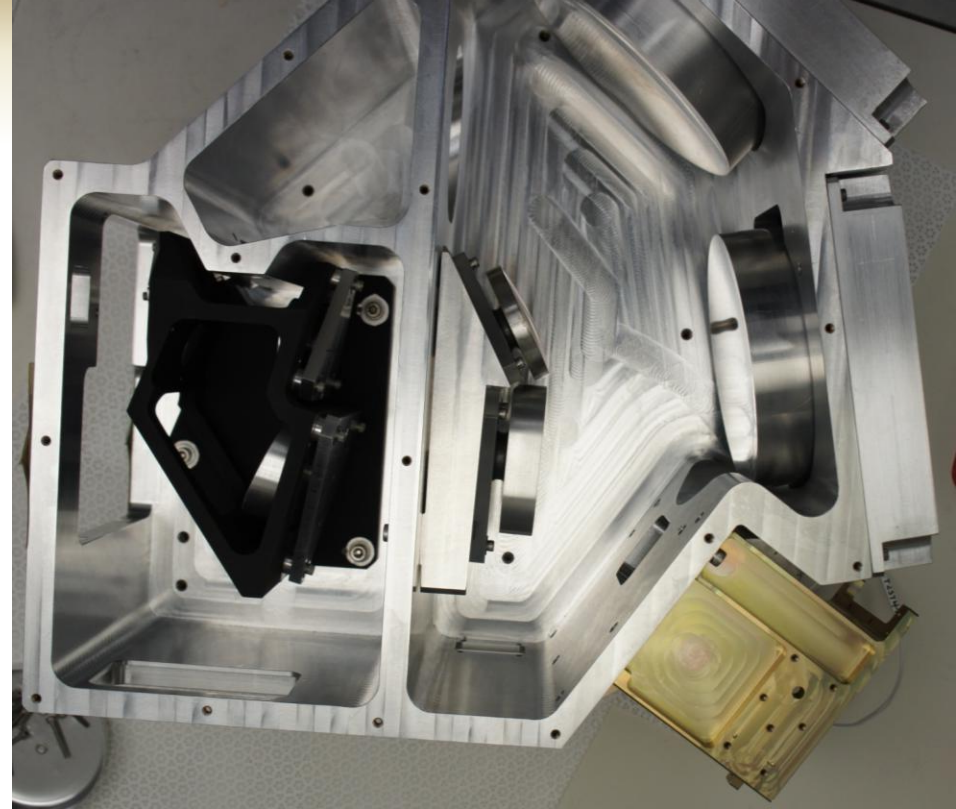


Optics set in shipping container

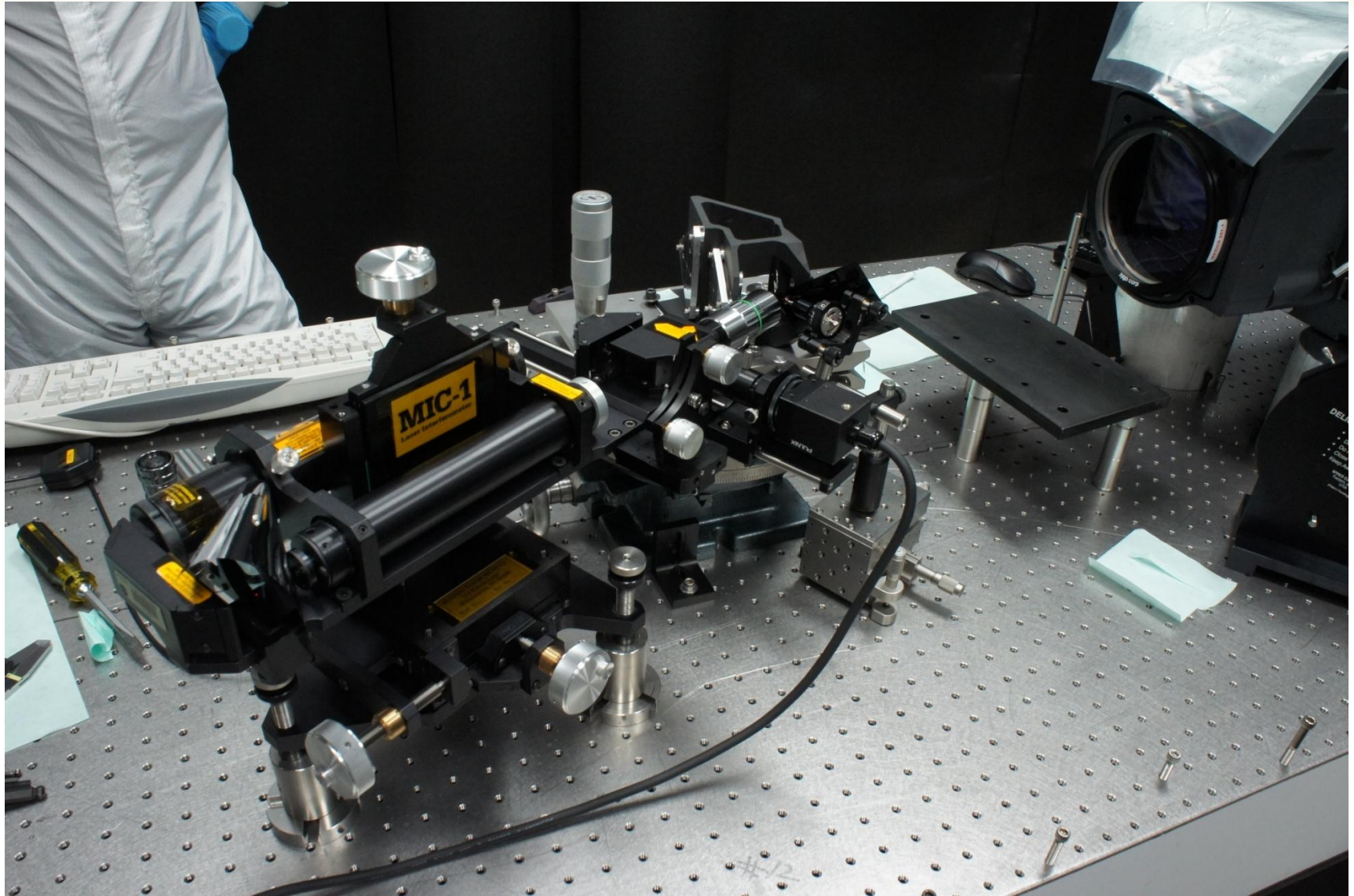
Complete Main Housing with Telescope Assembly



CDU Assembly with Optics

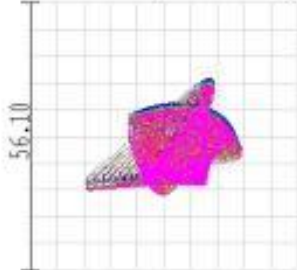


Telescope PSF Measurement Setup



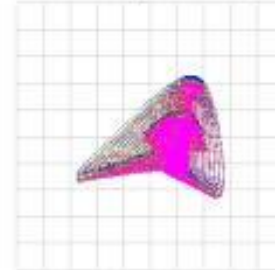
Telescope modeled image at the slit

OBJ: -4.7600, 0.0000 (deg)



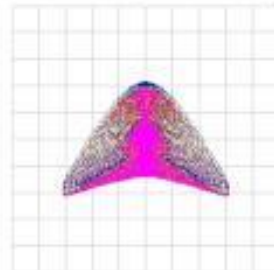
IMA: -7.501, 0.015 mm

OBJ: -2.3800, 0.0000 (deg)



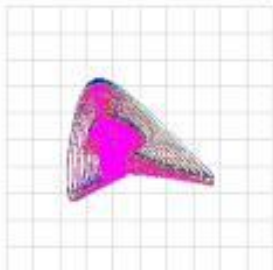
IMA: -3.753, 0.011 mm

OBJ: 0.0000, 0.0000 (deg)



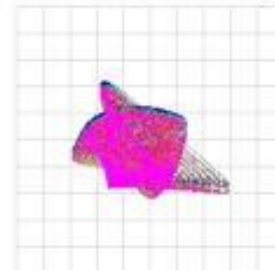
IMA: 0.000, 0.010 mm

OBJ: 2.3800, 0.0000 (deg)



IMA: 3.753, 0.011 mm

OBJ: 4.7600, 0.0000 (deg)



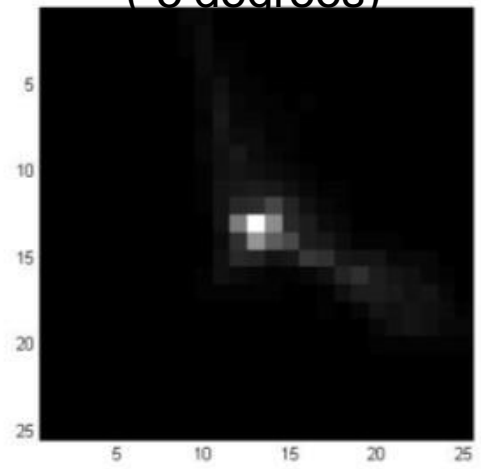
IMA: 7.501, 0.015 mm

Surface 31: Slit

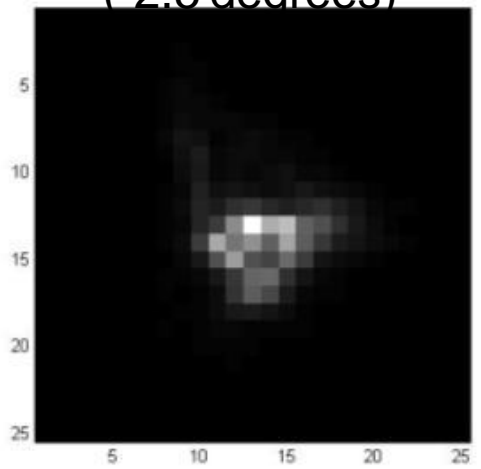
Spot Diagram

Measured point spread function

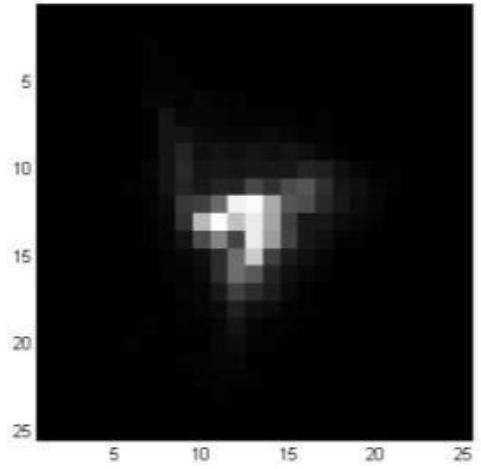
T50
(-5 degrees)



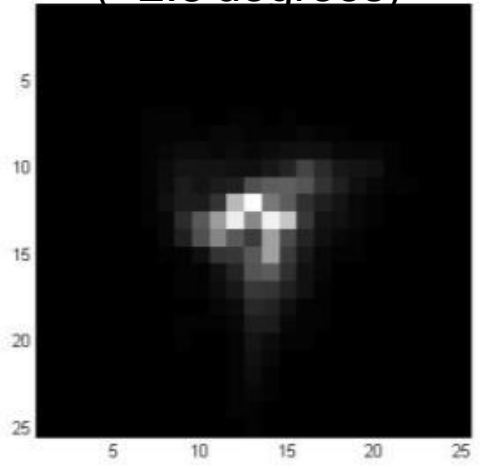
T25
(-2.5 degrees)



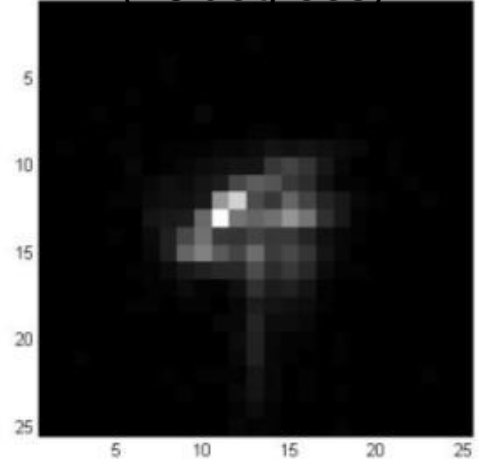
M00



B25
(+2.5 degrees)



B50
(+5 degrees)

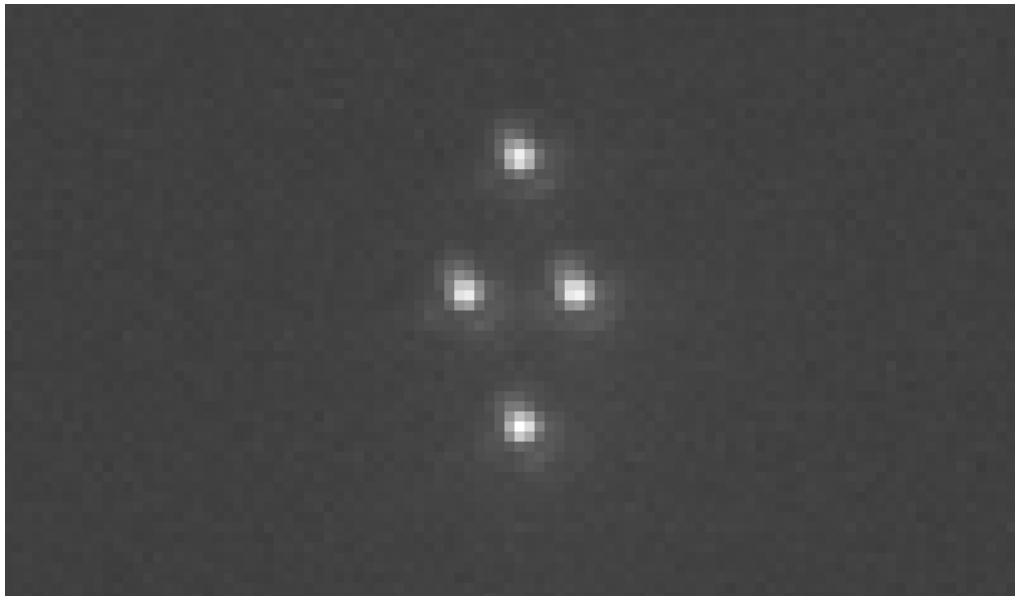


55 μ m

Depolarizer Output Image

490 nm wavelength 10 nm bandpass filter
Image of 5 micron pinhole through depolarizer

Result matches analytical prediction

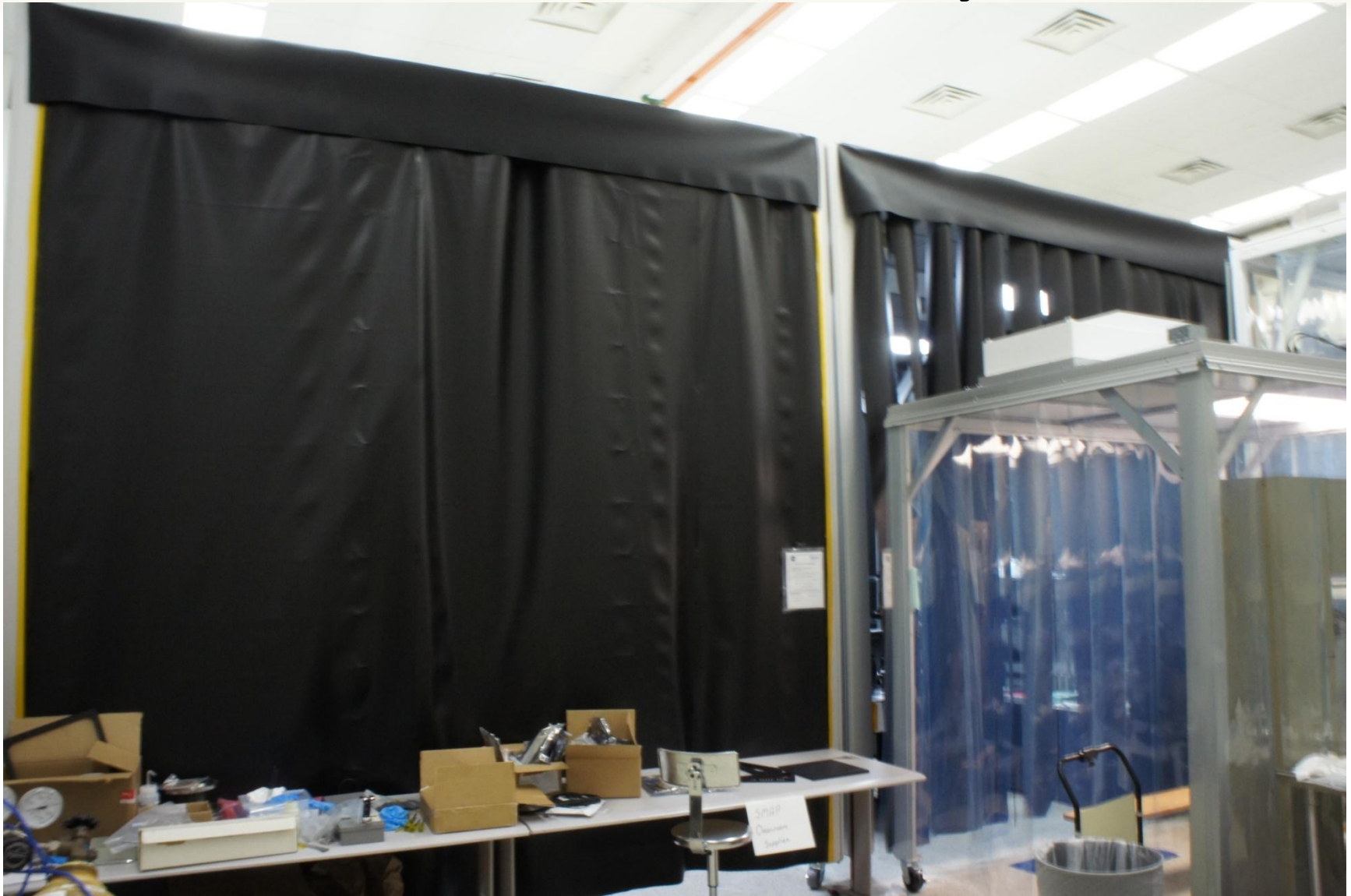


Left right spot separation 22 microns (10 pixels)
Top bottom spot separation 60 microns (27 pixels)
Pixel pitch 2.2 microns

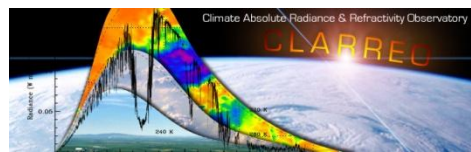
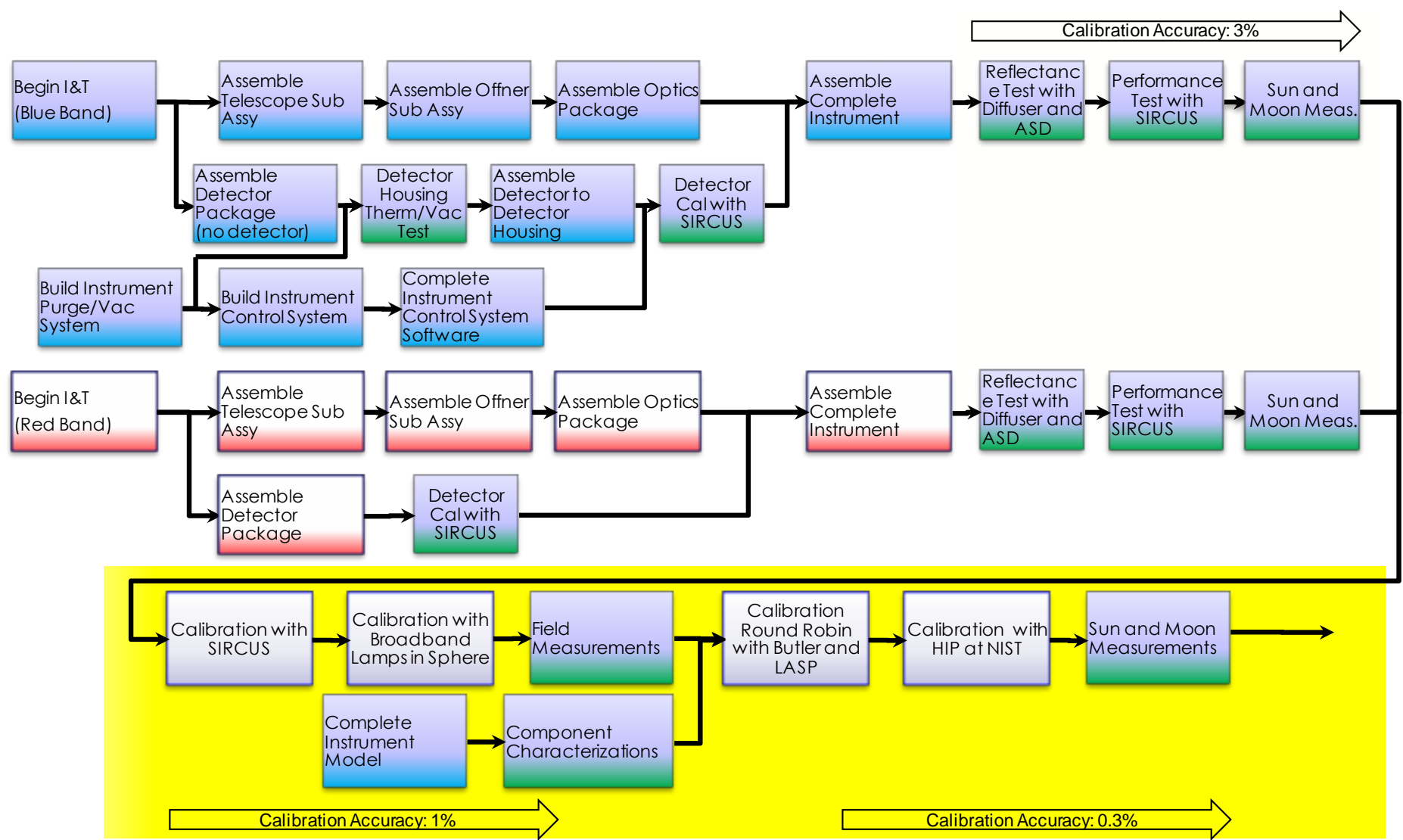
Thermal and Data Control Racks and tripod mount



Cleanrooms in OCL for CDU Assembly + Cal



CDS Integration, Test, & Cal. Flow



Summary

SOLARIS CDS will play a key role demonstrating CLARREO-quality error budgets

- Collaborative efforts with NIST continue to be critical
 - “Operational” use of SIRCUS
 - Extension to wavelengths >1 micrometer
 - Broadband calibration approaches (HIP)
- Calibration approaches will be demonstrated
 - Hence the “CDS” name
 - Laboratory calibration protocols
 - Error budget demonstration
- Reflectance retrieval
 - Stray light characterization
 - Instrument model assessment

